Topic: Shipping
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A DECISION SUPPORT METHOD FOR ANALYSING A SHORT SEA SHIPPING LINK FROM A PORT INFRASTRUCTURE PERSPECTIVE

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Abstract:

Today, freight volumes on roads have gone up to a level that there is a demand for alternative transport modes. Short sea shipping has been argued as one alternative that can help reduce the high traffic on roads. In general, there are two types of ships employed either roll-on roll-off (RoRo) or lift-on lift-off (LoLo) for short sea shipping. Most RoRo ships are used for "roll on and off" using a ramp with very small capacities usually less than 500 TEU, but with increasing cargo traffic, it is not clear if such solutions will be efficient. For ports involved in short sea shipping to meet up this new wave of change, the challenge to make appropriate investments and analysis tools is important. The type of vessel suitable for a short sea shipping operations (RoRo or LoLo) etc) has been addressed in this paper based on their compatibility and cost effectiveness with the terminal equipment.

The purpose of the research is to develop an optimization model that can be incorporated into a Computer Decision Support System (DSS). The proposed DSS model is used for selecting resources, such as equipment types and configurations and ship types at a strategic level for port infrastructure investments at port terminals in the context of short sea shipping. The results from the model indicates that a LoLo vessel with a capacity between 500 and 1000 TEU is capable of completing a voyage when considering handling is done within 48 hours will be less costly than a RoRo solution for TEU volumes greater than 1000.

Keywords: Short Sea Shipping, Optimisation, ILP, Integer Linear Optimization Model, Port Equipment

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1. INTRODUCTION

A main objective of the European Union's (E.U.) *Motorways of the Sea* initiative is to increase the use of intermodal freight, seaports and terminals in order to take more freight traffic off the road and rail systems (Everett 2006). The enlargement of the European Union, especially in the East Baltic region offers many tantalizing opportunities and uncertainties for policy makers regarding to the choice of freight transportation systems and transport corridors. The investments and business decisions on seaports, rail networks, and roads in moving cargo between the new members states in the Baltic incites many questions that require further analysis. In particular, the terminals or seaports require much attention and need to be studied since they are the "nodal points" between the land-based transport networks and marine transport networks. The terminals are often not explicitly taken into account when cargo transportation flows are analyzed at a regional level (Kondratowicz 1996).

The economies of the Baltic Sea Region countries are growing faster than the EU average. In addition, regional co-operation is shifting from the provision of support by Western countries (W-BSR) to their Eastern neighbors (E-BSR) - to a more balanced exchange. One of the main reasons is the constantly increasing trade within the BSR, with an estimated population of 100 million, driven by deregulation and removal of many customs administrative procedures in the new EU member states and inflow of foreign direct investments to these countries.

Over the recent decades the co-operation between local, regional and national governments in the Baltic Sea Region has been rising and has received additional support from EU enlargement. Intermodal links in the East West Transport Corridor consider the links such as in Figure 1 and in more detail, Figure 2 illustrated the transport links; China/Far East/Black Sea using the Trans Siberian.

Figure 1. East West Transport Corridor reflected by its partnership geography

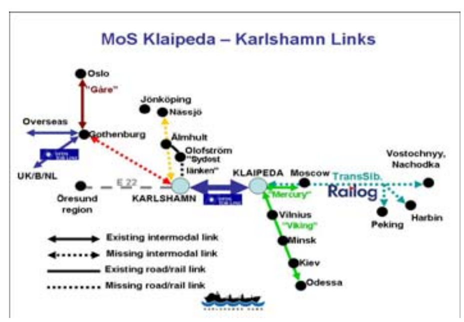

Figure 2. An attractive transport chain connecting east and west

1.1 Background

The growth of the international trade volumes of the BSR countries is expected to develop positively. Important activities includes to prepare investments in ports facilitating the intermodal transport chain, Modal shift towards more sustainable modes as rail and short sea shipping is promoted. Numerous challenges or bottle necks have been encountered in suggesting SSS solutions e.g. the lack of intermodal liability regime, unequal distribution of incentive measures, lack of comparable statistical data on SSS and other issues in relation to vessels speed and capacity, up to terminal handling and management issues. Managing cargo flows between ports and inland destinations has remained a challenge for terminal operators (Chadwin and Talley 1990; Notteboom 1997). Clearly, there is much attention on terminal operators to solve these issues. In order to reach their goals or objectives many terminal operators need technical assistance when selecting handling equipment from a strategic level for investments, tactical and operational level for deployment in order to manage their operations. The decision in selecting which equipment to invest or to deploy requires an integrated approach. The decision to invest on which equipment may not be difficult for terminals handling small volumes of cargo, however such a decision can be difficult to consider for different types of equipment, with increasing cargo volumes and stricter customer requirements, when several factors, such as congestion, performance, safety etc. needs to be taken into accounts.

The use of optimization tools can be formulated using linear relationships, thus we can model the system using a technique called Integer Linear Optimization Model (ILP). An ILP model for selecting handling equipment will enable port terminals such as Karlshamn and Klaipeda to preview what kind of handling tools shall be required as freight volumes increases at a strategic level. Based on demand forecast the tool can be suitable for choosing handling systems to deploy at tactical level. The aim is to model and represent the process of selecting terminal equipment including choice of ships in a unitized cargo terminal as an ILP based model. Based on the model we expect to be able to compare the performance of different handling systems by considering their cost and capacity. Regarding to handling system performance we expect to be able to suggest suitable shipping systems between LoLo and RoRo for SSS at different capacity levels.

1.2. Handling Systems and Performance Measure

How well a terminal is performing can be a difficult issue to address since terminals share variable goals especially public oriented terminals with a public welfare interest as opposed to private oriented terminals with a profit oriented interest. As pointed out by Ramstedt (2005), different types of performance measures could be used for different purposes, identifying here the quantitative, e.g. costs and the qualitative, e.g. environmental elements. In the case of container terminals high productivity has been an attractive performance aspects but often these are associated with rising costs which is less acceptable. The gap between these two aspects cost and capacity can be used as a measure of the competitiveness of the entire terminal, the greater the gap, the more competitive and better off is the terminal and vice versa. However several approaches have been used over the years, such as (Holguin-Veras and Walton 1996) to estimate terminal performance:

- Moves Per Hour; Within known geometric distances, the performance of handling equipment can be estimated as the number of TEU moved in one hour. This is often the preferred performance measure associated to equipment by production industries.
- Ship Distribution at Ports (SDP): SDP relies on the assumption that the berth occupancy analysis can be performed using the observed ship distribution at ports and, consequently, the number of ships at port is an independent random variable.
- Queuing Theory (QT): In general, the majority of QT applications consider only the ship-berth interface. In these applications basic QT, i.e., berth-dead processes in equilibrium, has been used to provide performance estimates. Other classes of QT models, e.g., queuing network and cyclic queues, have only been sporadically applied
- Simulation Applications: Simulation is increasingly being used today as a powerful tool to estimate the performance of port terminals. However, the time demanded by simulation models and the limited depth to which physical reality lends itself to abstraction has

limited efforts on simulation. Some recent port simulation studies include Multi-Agent Based Simulation (MABS) to enhance terminal performance (Henesey 2004), simulation of container queues for port investments (Alatar et al. 2006).

A more generalized performance measure for ports has been suggested to be “the average number of calls and the average flow volume or weight of goods over a standard period of time; number of calls per berth and per year, volume or weight of cargo handled per hour, per call or per day, per gang or per crane” (Fourgeaud 2000). In addition to these, other important factors worth considering in trying to estimate the performance of container terminals includes ratio of loaded to unloaded containers at any one point in time, unproductive moves, such as reshuffling of containers, level of automation of gantry cranes, average weight of containers, berth length, total waiting time of equipment as well as environmental effects such as quality of fuel or use of electric energy. All the above factors cannot be considered simultaneously, in a practical situation one has to choose few but sufficient factors necessary to meet the goals in consideration. Our interest however is on the performance of the individual equipment, how it affects the performance of the terminal at large. Consequently, in this study we consider mainly relative performance of equipment measured in moves per hour by introducing cost penalties involved in handling when various equipment are used, then formulating the problem as an integer linear optimization (ILP) model, and solving to determine which equipment types perform better at different capacity levels.

2. CASE STUDY

We aim at developing a decision support tool that addresses a real decision problem in selecting handling equipment in the context of a case study for the ports of Karlshamn and Klaipeda, which are a part of the East West Transport Corridor Research Project. Our interest mainly was on unitized cargo transported between the Port of Karlshamn, Sweden and the Port of Klaipeda, Lithuania that are illustrated in Figure 3.

Figure 3 Karlshamn-Klaipeda link over the Baltic Sea

Marine Leg Karlshamn-Klaipeda

For a ship with an average speed of 18 knots, it takes approximately 15 hours to cover the 223 sea miles distance as depicted in Figure 3, from the port of Karlshamn to the port of Klaipeda, thus completing one round trip every 48 hours. Currently, a minimum of two ships (LISCO Patrias & LISCO Kaunas) offer a RoPax service between Karlshamn and Klaipeda and are scheduled such that one ship makes a call at the port of Karlshamn while the other calls at the port of Klaipeda almost daily. Several reasons accounts for the importance of the Karlshamn Klaipeda shipping link:

- Connects Sweden and the Baltic States.
- Meet the EU SSS goals.

- Connect several old important transport routes, such as Corridor IX running south from Klaipeda to the Black Sea and Iran and also the Trans Siberian Corridor running East via Moscow towards India and China.
- The link connects to a strategic SSS network over the Baltic that offers support in effective trade within the Baltic States and Europe.
- The link can be regarded as part of the most active waterways across the Baltic given that it is cutting across high traffic shipping links connecting Russia with other European countries such as Holland, Germany and Denmark etc.

3. MODELING USING INTEGER LINEAR PROGRAMMING (ILP)

With a given demand of inbound/outbound TEU volume at a container terminal several decisions regarding different equipment needs to be considered. These decisions are interconnected and in most cases decisions about given equipment usually has a direct or indirect influence on decisions about other equipment. One of the very early decisions is the vessel choice with respect to the type and capacity appropriate for transportation. Once the appropriate vessel(s) have been chosen, it then becomes necessary to provide complementary facilities at the port of call that can service the vessel upon arrival. Thus a given choice of vessel will influence a decision on berth usage in case the vessel is a LoLo and ramp in case the vessel is RoRo or RoPax. For the chosen berth(s), the appropriate type and number of quay cranes will be selected. Quay cranes will need yard vehicles to move the containers, thus a decision about quay cranes will have an influence on the decision about yard vehicles. Yard vehicles will require yard or mobile cranes to off load the containers, thus selecting yard vehicles enforces the decision about yard cranes and the whole process can be followed way down the handling chain until the cargo units are loaded into the truck for outbound transport or onto the ships in case it is inbound.

In an optimization model we combine all the different restrictions about the entire system and seek for non-conflicting optimal decisions values. In Figure 4 is our proposed simple generic ILP model represented as a tree. The entire process has been simplified to enable model clarity given that there are a multitude of constraints which must be satisfied before a solution can be obtained

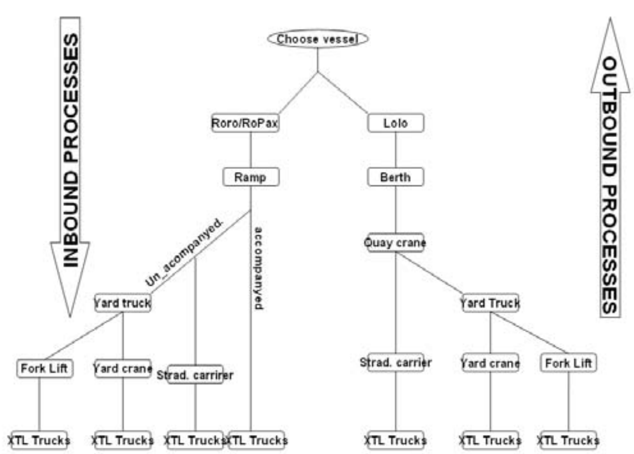

Figure 4 Simple generic ILP Model represented as a tree

The generic model as shown above can possibly be applied to most port terminals since the main handling systems for SSS are either RoRo/RoPax or LoLo services and handling operations are roughly in the same order, except for some cases that employ use of special purpose tools e.g. in automated terminals. The tree can be expanded to incorporate a wide range of terminal equipment. However, the parameters under which the equipment selection is optimized can vary greatly from one port to another, likewise the constraints governing operations.

3.1 Model Description

Optimization models represent problem choices as decision variables and seek values that maximize or minimize objective function of the decision subject to constraints on variable values expressing the limits on possible decision choices (Radin 2000). If such a model can be described using a linear objective function together with linear constraints then it is termed a linear program. If in addition all decision variables are discrete (binary or integers), then the model is referred to as an integer linear program. Nearly all optimization models are based on some assumption justifiable enough to represent a good approximation of physical reality. The validity of the optimal solution will depend on how well or to what extent the assumptions hold.

3.2 ILP Fundamental Assumptions

i. *Static Parameters;* All parameters used in the ILP model are assumed static and deterministic with respect to different capacity changes and also with respect to time.
ii. *Demand;* In particular, we assume that the demand (in TEU), for which equipment are needed is deterministic. Our goal is to select suitable equipment on a strategic base, that can handle a given demand volume (TEU).
iii. *Loading/Unloading;* We assume both processes of loading and unloading to be the same, practically, the handling of loading and unloading of cargo slightly differs. The reason is because our interest is on capacity issues which demand the same handling equipment both in loading and unloading.
iv. *Equipment Performance;* The average performance of each equipment has been estimated based on three factors, namely the distance to which the equipment has to move when in operation, the load carrying capacity of the equipment, and the preferred total number of hours the terminal operate. Where the terminal has a 24 hour operation in a day, the equipment is regarded to perform at it maximum output.
v. *Yard Capacity;* We assume the total area of yard allocated for stacking inventories can be calculated.
vi. *Time Window t;* While the model time window can be adjusted, we assume that for SSS operations it is necessary to consider small time windows (e.g. 48 hours) for handling.
vii. *TEU Calculation;* Vessel's carrying capacity has been considered in TEU units, and each trailer has been converted to TEU equivalent (in this case 2 TEU).
viii. *Full Load and Half Load;* In simplifying the model we chose to consider a 50% and 100% utilization levels of ship loading, which can be parameterized if necessary.
ix. *Distance traveled by yard equipment in yard;* we assume that all yard equipment used to transport containers travels approximately the same distance in estimating their performance.

Decision Variables

At a given value of TEU demand D, we decide on the optimal values of the following:

- Type and number of equipment to use at terminal e.g. Quay cranes, Yard cranes, Fork lifts, Yard Vehicles etc.
- Type, number and load utilization of vessel (ship) to use for transportation e.g. RoRo/RoPax ships, LoLo ships etc.
- Number of trucks to use for outbound TEU.
- Number of train blocks.
- Number of berths and ramps to use.
- Number of yard blocks required to line and/or stack containers.

Objective

Our objectives include the following;

- Minimize the total cost incurred as a result of the different choices of equipment needed, by selecting the most cost effective system.
- Minimize cost of transport from both shipper and terminal perspective by suggesting vessel choice that incur minimal cost at terminal e.g. an all RoRo solution, or all LoLo solution or a combination both.

Hence summing all these together we get:

Minimize Z = handling cost + transport cost

Where we suggest considering;
Handling cost = fuel cost + administrative cost + insurance cost + labor cost +
Transport cost = fuel cost + berth cost or ramp cost + insurance cost + consumables +
Several other parameters can be included to the above.

Constraints

i. *Demand;* All TEU demand should be satisfied by the chosen transport.
ii. *Demand Equipment;* All TEU demand should be satisfied by the chosen set of handling equipment.
iii. *Demand Trucks and Train;* Based on TEU demand, there should be sufficient truck and train capacity to serve the terminal.
iv. *Quay Cranes per Vessel;* There is a limit to the number of quay cranes that can service each LoLo vessel at a time and no quay crane is used to handle cargo transported in a RoRo vessel.
v. *Accompanied RoRo Trailers;* If TEU volume is accompanied, handling equipment are not used.
vi. *Ships per berth;* There is a limited number of ships using one berth at the same time.
vii. *Ships per ramp;* There is a limited number of ships using one ramp at the same time.
viii. *Yard Vehicles per Quay crane;* There is a limit to the number of yard vehicles that can be served at the same time by each Quay crane.
ix. *Yard Vehicles per RoRo;* There is a limit to the number of yard vehicles that can serve a RoRo vessel at the same time.
x. *Yard Vehicles per Yard crane;* Only a certain number of yard vehicles are allowed to serve a yard crane at the same time.
xi. *Trucks per loading equipment;* loading equipment such as yard crane can only process a certain number of trucks at a time.
xii. *Train per loading equipment;* The number of loading equipment processing each train blocks at a time is limited due to congestion.

xiii. .*Non-stacking equipment per container block;* in using equipment to lay container blocks, only a certain number of equipment can be selected for use in one block at the same time.

xiv. *Stacking equipment per container block;* in selecting equipment to stack containers, only a certain number of equipment can be selected for use in one stack at the same time.

xv. *Blocks allocated to containers;* If yard is not full, then unaccompanied containers and those not transported by truck and train has to be aligned in blocks.

xvi. *Stack Blocks allocated to containers;* If yard is full, then unaccompanied containers and those not transported by truck and train has to be stacked in blocks.

xvii. *Container blocks limited by yard:* The number of container blocks lined in yard depends on the allocated yard area.

xviii. *Usage of equipment;* If equipment is used a fixed cost is incurred.

xix. *Usage of facilities;* if berth or ramp is used then a fixed cost is incurred.

Since the model is complex, it was studied more as sub models consisting of terminal model (main model), yard model (for yard utilization), and yard discharge model (for intermodal) all build into a single model shown above.

ILP Mathematical Formulation

We consider the sets represented by the following;

Set I represents the set of all handling equipment used in the terminal.

Set QC $\subset I$ represents the set of quay cranes used in processing ships.

Set YC $\subset I$ represents the set of all yard cranes used in terminal.

Set L $\subset I$ represents the set of all loading equipment used in terminal.

Set M $\subset I$ represents the set of all terminal equipment used in stacking containers.

Set P $\subset I$ represents the set of all terminal equipment used in laying blocks, no stacks.

Set YV $\subset I$ represents the set of all yard vehicles used in terminal.

Set J represents the set of all vessels or ships used for transport.

Set LOLO $\subset J$ represents ships used in transportation that are only LoLo.

Set RORO $\subset J$ represents ships used in transportation that are only RoRo.

For each given equipment $i \in I$, we consider parameters represented by:

- CE_i: Costs of equipment $i \in I$ based on; fuel consumed, labor, fixed cost (administration, energy, etc), insurance, repair and maintenance etc., all within a given time window (e.g. 24 hours).
- Av_i := (TEU moves per hour) *(Time Window) for equipment i $i \in I$
- f_i := fixed cost incurred in using equipment i, $i \in I$

For each vessel j $\in$ J we consider parameters represented by:

- CV_j: Costs of vessel j $\in$ J based on crew costs, consumables, port dues, cost of fuel, repair and maintenance, insurance etc within a given operation.
- As_j := average TEU capacity for vessel j, $j \in J$
- f_j := fixed cost incurred in using vessel j, $j \in J$

We further consider the following parameters;

- D := TEU demand.
- Time Window := the length of time in hours to complete handling.

- AT := ratio of accompanied TEU volume in RoRo vessel.
- B_{max} := number of vessels per berth for the time period.
- R_{max} := number of vessels per ramp for the time period.
- VQ_{max} := number of quay cranes that can load/unload each vessel at a time.
- QV_{max} := number of yard vehicles a quay crane can load/unload at a time.
- RV_{max} := number of yard vehicles per RoRo vessel
- YV_{max} := number of yard vehicles per yard crane.
- RT := number of trucks allocated to loading equipment at the same time.
- RN := number of train allocated to loading equipment at the same time.
- TC := average truck capacity.
- NC := average capacity for each train block.
- EG := allowed number of equipment per container block, no stacks.
- ES := allowed number of equipment per container block with stacks.
- CY := container yard allocated to lining and stacking containers.
- CA := area occupied by one container block.
- Z := number of containers in one block lined in time t.
- ε := 0.0001, a small number to minimize number of trucks and train.
- M := arbitrarily large number (e.g. 1000000), to control binaries.

The following variables are used in the model (i.e. determined by optimization):

$0 \leq Y_j$ integer, vessels or ships, $j \in J$.
$0 \leq X_i$ integer, terminal handling equipment $i \in I$.
$0 \leq$ R integer, number of ramps.
$0 \leq$ B integer, number of berths.
$0 \leq$ K integer, number of trucks required.
$0 \leq$ N integer, number of train blocks required.
$0 \leq$ G integer, container blocks on yard, no stacks.
$0 \leq$ S integer, stacked container blocks on yard.
$0 \leq Br_j$ binary, is 1 when transport Y_j is used and zero otherwise, $j \in J : RORO$.
$0 \leq Bl_j$ binary, is 1 when transport Y_j is used and zero otherwise, $j \in J : LOLO$.
$0 \leq Be_i$ binary is 1 when equipment X_i is used and zero otherwise, $i \in I$.

Minimize (ILP)

$$Z = \sum_{j \in J} CV_j * Y_j + \sum_{i \in I} CE_i * X_i + \sum_{i \in I} f_i * Be_i + \sum_{j \in RORO} f_j * Br_j + \sum_{j \in LOLO} f_j * Bl_j + \varepsilon(K + N)$$

Subject to the following constraints;

i. Demand transport $\sum_{j \in J} As_j * Y_j \geq D$

ii. Demand Equipment: $\sum_{i \in I} Av_i * X_i \geq D$

iii. Demand Trucks and Train: $K + N \geq (D - (1 - AT) * \sum_{j \in RORO} As_j * Y_j)$

iv. Quay crane per vessel : $VQ_{max} * Y_j \leq \sum_{i \in QC} X_i$, $j \in J : LOLO$

v. Accompanied RoRo Trailers $\sum_{i \in YV} Av_i * X_i \geq (1-AT) * \sum_{j \in RORO} As_j * Y_j$

vi. Ships per berth: $\sum_{j \in LOLO} Y_j \leq B_{max} * B$

vii. Ships per Ramp: $\sum_{j \in RORO} Y_j \leq R_{max} * R$

viii. Yard Vehicles per Quay crane: $QV_{max} * X_j \leq \sum_{i \in YV} X_i$, $j \in QC$

ix. Yard Vehicles per RoRo: $RV_{max} * Y_j \leq \sum_{i \in YV} X_i$, $j \in RORO$

x. Yard vehicles per yard cranes $YV_{max} * X_j \leq \sum_{i \in YV} X_i$, $j \in YC$

xi. Trucks per loading equipment: $RT * X_i \leq K$, $i \in L$

xii. Train per loading equipment : $RN * X_i \leq N$, $i \in L$

xiii. Non-stacking equipment per container block : $EG * G \leq \sum_{i \in P} X_i$

xiv. Stacking equipment per container block: $ES * S \leq \sum_{i \in M} X_i$

xv. Blocks allocated to containers : $G * Z \geq (D - (1-AT) * \sum_{j \in RoRo} As_j * Y_j)$

xvi. Stack Blocks allocated to containers; $S * Z \geq (D - (1-AT) * \sum_{j \in RoRo} As_j * Y_j)$

xvii. Container blocks limited by yard; $G * CA \leq CY$

xviii. Usage of equipment: $X_i \leq M * Be_i$, $i \in I$

xix. Usage of ship's facilities:

a) Control cost of ramp: $Y_j \leq M * Br_j$, $j \in RORO$

b) Control cost of berth: $Y_j \leq M * Bl_j$, $j \in LOLO$

4. RESULTS AND ANALYSIS

In making a decision on the choice of handling equipment to invest on or to deploy for an operation, one key issue to consider is how much TEU capacity there is to be handled. We assume as said earlier that the TEU demand is known in advance. Based on this capacity, it is important, that handling is completed within a time window that will meet customer demands. We have considered a 48 hour maximum for the time window because one trip for our case study for Karlshamn-Klaipeda-Karlshamn is completed within 48 hours. This time window is then used by the ILP model to calculate for each handling equipment the average capacity output and some cost parameters, such as fuel, labor etc. Handling equipment could vary greatly in terms of restrictions laid on operations and operational cost incurred. We consider the case for the most common and yet highly useful equipment such as quay cranes, fork lifts, yard vehicles, yard cranes, tugmasters etc.

To configure the model to suit the case study for the paper, interviews and discussions were conducted with some representatives of the port of Karlshamn and port of Klaipeda with expert knowledge on unitized cargo handling. Thus we configure our model based on information obtained from these interviews.

i. Incremental increase in demand of 100TEU for each scenario.
ii. An average distance of 400m from container location to destination is considered in estimating the performance values for transfer equipment (yard vehicles).
iii. More than half of the inbound/outbound TEU capacity is considered to be handled by truck and train at variable ratios, in an intermodal operation.
iv. About half of the RoRo container traffic volume is accompanied.
v. A truck or trailer has a capacity equivalence of 2 TEU and train block an equivalence of 4 TEU for full capacity.
vi. Each LoLo vessel may be serviced by 1, 2, or 3 quay cranes in a single 1 berth.
vii. Each RoRo is associated a ramp during handling and one ramp can be used by two RoRo ships within the time window considered.
viii. The container yard area in this case was taken to be about 3000 square meters.

Since the cost incurred by external trucks and train are not part of the terminal cost, it was left out from the parameters considered. In Table 1, we present some estimates of parameters used in our model. The total cost is the sum calculated per day including capital cost of equipment.

Table 1 Model parameters *Source: ports of Karlshamn, Klaipeda and literature*

Equipment	Performance	Cost Total/day)SEK
Quay Crane	(30-32)TEU/hour	119592
RTG	(28-35) TEU /hour	40656
Tugmaster	(13-25) TEU /hour	34056
Fork lift	(23-32) TEU /hour	33480
Trailers	(8-20) TEU /hour	10920
Mafis	(7-18) TEU /hour	3120
Straddle Carriers	(32-42) TEU /hour	51336
Contchamp	(28-38) TEU /hour	56280
RoRo150	(150-200)TEU	234637
RoRo200	(217-240) TEU	271582
RoRo250	(252-320) TEU	293807
RoRo350	(352-390) TEU	327032
LoLo500	(400-500) TEU	250110
LoLo1000	(800-1000) TEU	343708
LoLo1500	(1300-1500) TEU	375576
Truck capacity	2 TEU	N/A
Train capacity	4 TEU	N/A

The ILP model output is presented as an instance of the generic model shown above (Table 1) with equipment type and number for different TEU volumes. In addition, the type and number of vessels, trucks and train capacities are also displayed. We interpret these results as a suggestion for which equipment to invest on i.e. strategic level decision. Based on the nature of the demand the model can be useful for tactical level decision planning in deploying already existing equipment in an optimal set up that minimizes redundancies. The required facilities such as berths, ramps and container blocks lined in yard are also estimated. In the following tables (Tables 2 & 3), we present results for a given range of demand values (0-2000 TEU), iterating at demand levels of 100 TEU, the results for 21 scenarios are displayed on the table below. The handling time window is considered to be the time during which handling must be completed, and the equipment are therefore selected to complete handling within this time window.

Key to Tables 2 and 3

QC = Quay Crane SC = Straddle Carrier RTG = Rubber Tyred Gantry YV = Yard Vehicle (terminal trailers and mafis) FL = Fork Lift	TM = Tugmaster RS = Reach Stacker (Contchamp) Lxxx = fully utilized LoLo capacity xxx TEU Lxxx* = half utilized LoLo capacity xxx TEU Rxxx = fully utilized RoRo capacity xxx TEU Rxxx* = half utilized RoRo capacity xxx TEU	Rm = Ramps Bt = Berths G=non-stacked container blocks S = stacked container blocks Tcost = Total cost of operation

Table 2 Output results with Handling Time Window = 24 Hours (50% accompanied for all RoRo volumes)

TEU	Ship Type		Equipment							Facilities				Tcost (SEK)
	RoRo	LoLo	QC	SC	RTG	YV	FL	TM	RS	Rm	Bt	G	S	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
100	R150*	0	0	0	0	2	1	2	1	1	0	5	0	812604
200	R150	0	0	0	1	4	0	3	1	1	0	10	0	824351
300	R250	0	0	0	1	4	0	3	1	1	0	15	0	864253
400	0	L500*	1	1	0	8	3	5	1	0	1	20	0	883516
500	0	L500	1	1	0	8	3	5	1	0	1	25	0	885016
600	R150	L500*	1	1	0	8	3	5	1	1	1	30	0	1077650
700	R150	L500	1	1	0	8	3	5	1	1	1	35	0	1079150
800	R250	L500	1	1	0	8	3	5	1	1	1	40	0	1119050
900	0	2xL500	2	2	1	16	4	10	1	0	2	45	0	1166980
1000	0	2xL500	2	2	1	16	4	10	1	0	2	50	0	1166980
1100	R200*R350	L500	1	1	0	8	3	5	1	1	1	50	5	1349230
1200	0	L500* L1000*	3	3	0	24	8	14	1	0	2	50	10	1354390
1300	0	L500 L1000*	3	3	0	24	8	14	1	0	2	50	15	1355890
1400	0	3xL500	3	3	0	24	8	14	1	0	3	50	20	1445200
1500	0	3xL500	3	3	0	24	8	14	1	0	3	50	25	1445200
1600	R250	L500 L1000*	3	3	0	24	8	14	1	1	2	50	30	1588560
1700	R250	3xL500	3	3	0	24	8	14	1	1	3	50	35	1637980
1800	0	2xL500 L1000*	4	4	0	32	11	19	1	0	3	50	40	1645020
1900	0	4xL500	4	4	0	32	11	19	1	0	4	50	45	1734330
2000	0	4xL500	4	4	0	32	11	19	1	0	4	50	50	1734330

Table 3 Output results with Handling Time Window = 48 Hours (50% accompanied for all RoRo volumes)

TEU	Ship Type		Equipment							Facilities				Tcost (SEK)
	RoRo	LoLo	QC	SC	RTG	YV	FL	TM	RS	Rm	Bt	G	S	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
100	R150*	0	0	0	0	2	1	2	1	1	0	5	0	848943
200	R150	0	0	0	1	4	0	3	1	1	0	10	0	869615
300	R350*	0	0	0	0	2	1	2	1	1	0	15	0	903300
400	0	L500*	1	1	0	8	3	5	1	0	1	20	0	1007130

500	0	L500	1	1	0	8	3	5	1	0	1	25	0	1008630
600	R250* R350*	0	0	0	0	2	1	2	1	1	0	30	0	1131960
700	R250 R350	0	0	0	1	4	0	3	1	1	0	35	0	1153470
800	R250	L500	1	1	0	8	3	5	1	1	1	40	0	1241300
900	0	L1000	2	2	1	16	4	10	1	0	1	45	0	1307180
1000	0	L1000	2	2	1	16	4	10	1	0	1	50	0	1307180
1100	2xR350R200	0	0	0	0	8	3	5	1	1	0	50	5	1470610
1200	0	L500* L1000*	2	2	1	16	4	10	1	0	2	50	10	1472070
1300	0	L500 L1000*	2	2	1	16	4	10	1	0	2	50	15	1473570
1400	0	L500* L1000	2	2	1	16	4	10	1	0	2	50	20	1475070
1500	0	L500 L1000	2	2	1	16	4	10	1	0	2	50	25	1476570
1600	R250	2xL500* L1000*	2	2	1	16	4	10	1	1	3	50	30	1639950
1700	0	2xL500 L1000*	2	2	1	16	4	10	1	0	3	50	35	1642950
1800	0	2xL500 L1000*	2	2	1	16	4	10	1	0	3	50	40	1642950
1900	0	2xL500* L1000	2	2	1	16	4	10	1	0	3	50	45	1834920
2000	0	4xL500	2	2	1	16	4	10	1	0	3	50	50	1835730

Table 4 Estimated numbers of trucks and train capacity (based on TEU volumes)

TEU	Trucks	Train
0	0	0
100	3	2
200	10	5
300	14	7
400	40	20
500	50	25
600	50	25
700	60	30
800	64	32
900	90	45
1000	100	50
1100	80	40
1200	120	60
1300	130	65
1400	140	70
1500	150	75
1600	144	72
1700	160	80
1800	180	90
1900	190	95
2000	200	100

Time Window = 24 Hours, 50 % accompanied for all RoRo volumes
Inventory := 40%
Truck Capacity := 2 TEU
Train Capacity := 4 TEU

TEU	Trucks	Train
0	0	0
100	3	2
200	10	5
300	13	7
400	40	20
500	50	25
600	30	15
700	35	18
800	64	32
900	90	45
1000	100	50
1100	55	28
1200	120	60
1300	130	65
1400	140	70
1500	150	75
1600	160	80
1700	170	85
1800	180	90
1900	183	92
2000	190	95

Time Window = 48 Hours, 50 % accompanied for all RoRo volumes
Inventory := 40%
Truck Capacity := 2 TEU
Train Capacity := 4 TEU

4.1. Output Analysis

From Tables 2 &3, the number of equipment varies with the number and type of ships used, since the equipment are selected to serve the ships. Changing the time window for handling changes the number of equipment selected since the workload estimate for equipment depends on their performances calculated in moves per unit hour. The model handles a wide range of issues, and as such, model output can be analyzed in several different ways depending on particular aspects of interest. Some analysis of interest, for example could include the following;

4.1.1 A Change at TEU 1100

Tables 2 & 3 shows that at 1100 TEU capacity point, there is a significant change in the type of vessel and equipment used. Such a situation can be difficult to handle if it hasn't been pre-aimed because investments at 1100 TEU level are shown to be less efficient at 1200 TEU level as can be seen from the results. By tuning model parameters to meet conditions at 1100 TEU capacity level, from the present TEU handling capacity, it can be possible to estimate the required investment rate in order to handle such changes. E.g. suppose the present handling volume is 200 TEU, then setting constraints at 1100 TEU volume, and running the model, results indelicate that an increase investment be made on RoRo vessels and yard vehicles. Such information can help the port to make reasonable trade offs that avoids future decision problems.

4.1.2. Choice of Vessel Versus TEU Volume

From Tables 2 & 3 LoLo vessels can be seen to be less efficient for capacities below 500 TEU compared to RoRo vessels. This is reasonable since LoLo vessels have huge capacities which shall be underutilized if used for TEU capacities less than 500. Above 500 TEU, it is possible to use both LoLo and RoRo but, LoLo will be more efficient than RoRo since about 70 % of the scenarios from 500 TEU upwards makes use of LoLo. However, the time window is a limit to the type of LoLo especially in relation to capacity. LoLo vessels with capacities more than a 1000 TEU can be difficult to serve a SSS system within a 48 hour handling time window. The variation of choice of vessel versus capacity can be shown using a simple bar chart (Figure 5 and Figure 6)

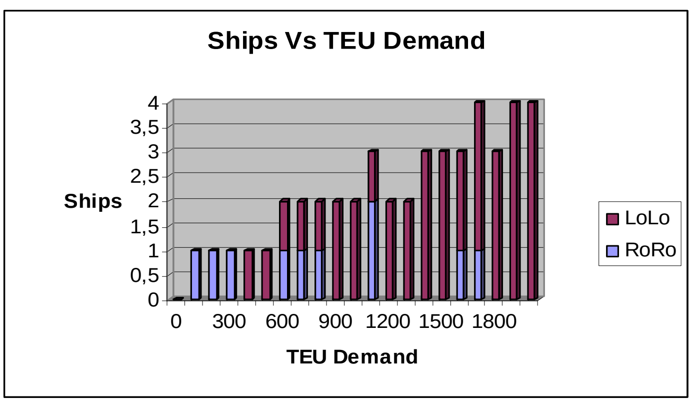

Figure 5 Variation in number of ships with TEU demand for a 24 Hour Handling Time Window

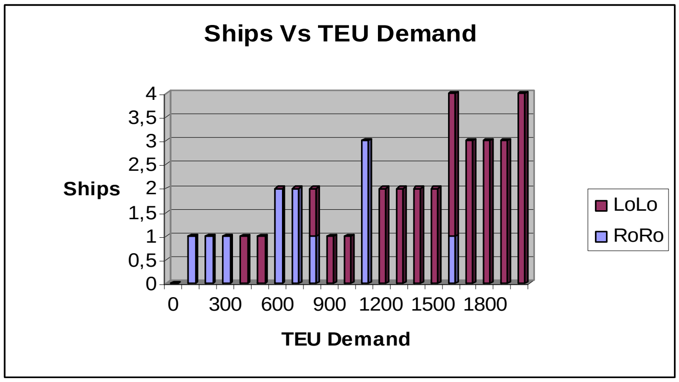

Figure 6 Variation in number of ships with TEU demand for a 48 hour handling time window

4.1.3. Choice of Vessel Versus Number of Yard Vehicles

When ever a RoRo ship is used for transportation, about 50% of the cargo is treated as accompanied for the above outputs. This means that the units are equipped with drivers to drive them out of the ship without the need for any handling. Consequently fewer types of equipment are used in RoRo operations than LoLo (shown in Figure 7).

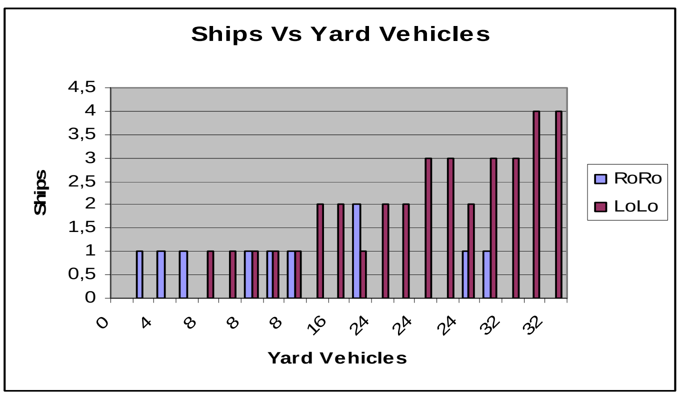

Figure 7 Variation in number and type of ships with yard vehicles

4.1.4. Effect of Handling Time Window

Increasing the time window from 24 to 48 reduces the number of equipment. This is because equipment are selected with respect to the total number of TEU moves required to complete handling. The TEU moves depend on the performance value of the equipment, calculated in moves per hour. As such, if the time window is increased then, less equipment shall be needed to handle the same amount of TEU than within a short time window. For the vessels the time window determines the choice of vessel from the required time to load/unload a vessel. The following figure (Figure 8) shows how the number of yard vehicles varies for a 24 hour handling time window, compared to a 48 hour handling time window for the same TEU volume

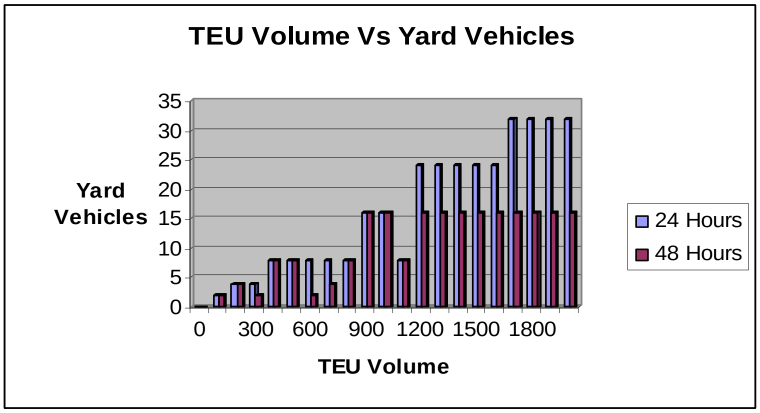

Figure 8 Variation in number of yard vehicles with TEU Volume for different handling time windows

Cumulative use of Equipment

If the port invests on given equipment, the equipment remains useful over a given period of time according to the depreciation period associated to the equipment. Therefore it is possible to use the same equipment at different TEU demand capacity levels within the depreciation period. Such a situation can be accommodated into the model or analyzed from the output i.e. the required set of equipment for the next 100 TEU capacity scenario is calculated taking into consideration the existing equipment. As an example, results from the 24 hour scenario (table 7-2) for investments in Quay crane, Fork lifts and yard vehicles, taking accounts of the already existing investments are shown on Figure 9 below;

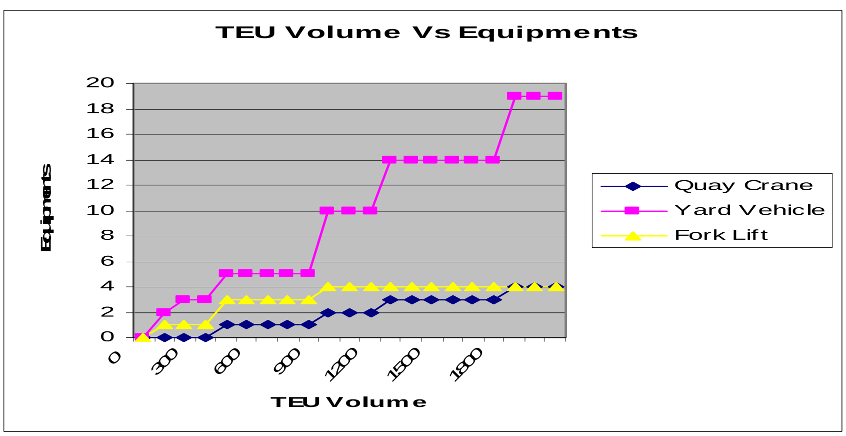

Figure 9 Cumulative reuse of equipment fork lift, yard vehicles and quay crane (from Table2)

For ships the depreciation period is usually very long, and a similar analysis is presented in Figure 10. The changes indicate the point at which to invest or negotiate for a new vessel and helps in making a choice between LoLo or RoRo solutions.

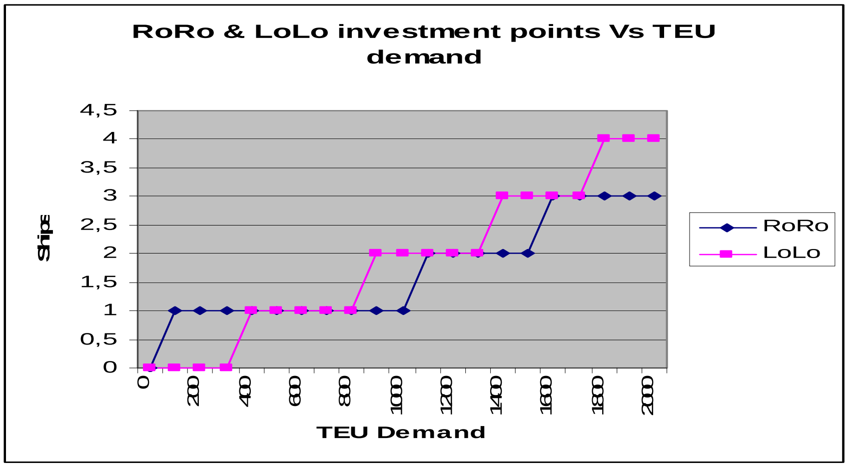

Figure 10 Investment points in ships with TEU demand (from Table 2)

Variation of Total Cost with TEU Volume

Analyzing how the total cost varies with TEU demand can enable the port to determine the appropriate pricing strategy to attain a given investment point from the present capacity point. E.g. suppose the port is at capacity level 400 TEU/day and forecast a need for an investment in order to be able to handle TEU demand 800 /day, then from the variation of total cost per TEU, it is possible to determine a benchmark for the appropriate cost/price per TEU to attain investments at demand level 800 TEU/day after a certain period of time. Figure 11 below illustrates the variation of total cost per TEU demand.

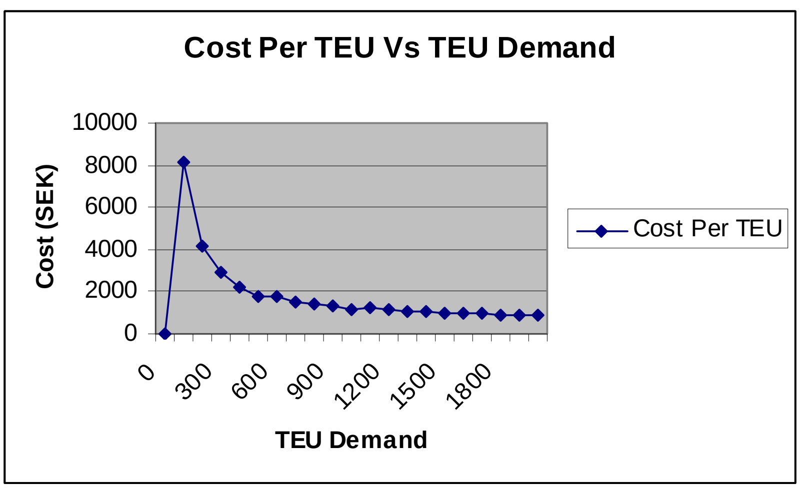

Figure 11 Variation of total cost per TEU (from table3)

Sensitivity Analysis

As part of the validation process of a model, it sensitivity can be studied by varying parameter values and constraints and significant effects of such changes monitored to draw conclusions about the behavior of the model. Validation of the proposed ILP model was done mainly by following the operational Research Process (Radon 2000) in which we obtain data from the real world, run the model, and compare the output with known practical solutions. The proposed model parameters were adjusted to suit the present practical scenario for the case study and results were quite similar to the practical case. A summary of some sensitivity analysis for the model is shown on the table below in Table 5.

Table 5 Analysis of model sensitivity

Test	Effect	Conclusion
Decreasing the time window to 6 hours	Increase use of RoRo ships for small capacities	Large capacity ships (LoLo), cannot be served within smaller time windows.
Increase in Time window to 60 hours	Increase use of LoLo ships for bigger capacities	A larger time window is suitable to serve larger ships
Increasing demand to 4000 TEU, time window 48 hours	Increase in number of equipment. The pattern from 0 to 2000 remains averagely the same for RoRo plus more LoLo ships from 2000 to 4000	The solution seems to be symmetric since all conditions were maintained.
Change in Container Yard capacity (CYC)	Increase in CYC increases the use of yard vehicles and non-stacking equipment and decrease in yard increase the use of stacking equipment	Increase yard will lead to use of non stacking equipment with less cost relative to stacking equipment and vice versa.
Relaxing the constraint on simultaneously serving LoLo vessels within 48 hours	Use of small capacity LoLo ships from 800 TEUs upward. The total cost is reduced	A sequential service where possible may be cost effective than a simultaneous service because investments in equipment may be more costly than labor
Limiting facilities to a maximum of 1 berth and 2 ramp, 48 hours, 2000 TEU	Increase total cost, 1 LoLo vessel and 2 RoRo vessels at 2000 TEU	Multiple RoRo solution at high capacity is more costly compared to LoLo solution.
Relaxing integer requirement, time window 48 hours	Model is solved with fractional values. For some scenarios the cost reduction is quite significant as much as 39% for scenario with TEU volume 1800	Depending on the penalty that will be incurred some equipment may not be suitable to invest on at certain demand levels

CONCLUSION

In order to meet European Union SSS requirements in delivering seamless intermodal solutions, it is absolutely necessary that port terminals and shippers consider cooperative strategies in order to minimize time and manage cost. An acceptable SSS solution will be one that serves time all across the entire transport chain from the shipper through the terminal and to the land transport, hence the need to study it as an integrated system. Integrated optimization models build into DSS will be useful in achieving such strategies. Further improvements can be made to the ILP model developed in this paper following the operational research process, and the model can be tailored to the needs of different port terminals at large.

In developing our ILP model we attempted to establish a methodology by which a complete decision support tool can be developed for a container terminal. The suggested methodology considers the integrated problem as made of sub problem models (yard, intermodal, yard discharge etc) all build into a single integrated optimization model through a number of operational research process (Radon 2000) iterations, until reasonable results are obtained.

Based on data obtained from the case study, the ILP Model results indicates that a LoLo vessel with a capacity between 500 and 1000 TEU capable of completing a SSS voyage within 48 hours will be less costly than a RoRo vessel with greater than 1000 TEU. Further improvement will be to develop the different models to consider the different activities in a considerable depth and include more models such as stowage optimization, a demand forecast, berth allocation strategies etc. The model can further be developed to consider all variations in cargo since we assumed that all cargo is unitized and can be stacked where LoLo is the vessel of choice. Trailers, though unitized, cannot be stacked and will only be transported in a RoRo vessel.

Other optimization modeling approaches such as non-linear programming can be applied to solve this same problem and results compared. Performance of different algorithmic codes in solving the problem modeled in this paper can be compared by applying these algorithms and comparing results. If the operational research cycle is iterated several times the model can further be improved to a full DSS with a suitable interface.

REFERENCES

Alattar, M.A., Karkare,B., and Rajhans, N. (2006). Simulation of container queues for port investments, Proceedings of the 6th International Symposium on Operations Research and Its Applications (ISORA’06) Xinjiang, China.

Ballis, A. and Golias, J. (2000). Towards the improvement of a combined transport chain performance, *European Journal of Operational Research* 152 (2) pp.420-436.

Beverskog, P., Edgren, P., and Jarlborg, A. (2003). EU Enlargement in the Baltic Sea; Consequences to the Swedish Ship Owners. Master Thesis No *2003* Gothenburg University.

Brooks, M.R., Hodgson, J., and Frost, J.D. (2006). *Short sea shipping on the east coast of north america: an analysis of opportunities and issues*. Canada–Dalhousie University Transportation Planning/Modal Integration Initiative Project ACG-TPMI-AH08.

Chadwin, M. P., and Talley, W.K. (1990). *Ocean container transportation, an operations perspective.* New York,New York: Taylor & Francis.

Darbra, R.M., Ronza, A., Stojanovic, T.A., Wooldridge, C., and Casal J. 2005). A Procedure For Identifying Significant Environmental Aspects In Sea Ports (SOSEA); Marine Pollution Bulletin.

Estache, A., Gonzalez, M., and Trujillo, L. (2002). Efficiency gains from port reform and potential for yardstick competition: lessons from Mexico. *World Development*, 30(4), pp.545-60.

Fourgeau, F. (2000). Measuring Port Performance: World Bank Report.

Francesc,S., Francesc, R., Ramon, J., and Andres, L.P. (2006). *Optimization of Handling Equipment in the Container Terminal of the Port of Barcelona, Spain*. Transportation Research Record: Journal of the Transportation Research Board (1963) ISSN: 0361-1981.

Gambardella, L. M., and Rizzoli, A. E. (2000). The role of simulation and optimisation in intermodal container terminals, Proceeding of the 12th European Simulation Symposium and Exhibition (ESS 2000), Hamburg, Germany, The Society of Computer Simulation International, pp.422-426.

Giannopoulos, G.A. (2004. The Application Of Information And Communication Technologies In Transport, European Journal of Operational Research 152 (2004) pp.302–320.

Guohua, W.WAN (March 2004); An Intelligent Decision Support System for Crane Scheduling in a Container Terminal, Applied Artificial Intelligence Vol. 20
Gunter, H.O. and Kim, K.H. (2005). *Automated Transport Systems: Logistic Control Issues of Transport.* Container Terminals and Automated Transport Systems. Heidelberg, Germany: Springer.

Hansen, B. (1996). CPT Container pallet transfer-an automatic high capacity ship/shore loading system. *Proceeding of the 3rd European Roundtable Conference on SSS,* Bergen, Norway, June pp.125-126.

Henry, Y. K. L., Ying, Z., and Chuanyou P. (2005); Integrated Scheduling of different Types of Handling Equipment at Automated Container Terminals, *Proceedings of the 2nd Multidisciplinary International conference on Scheduling, Theory and Applications (MISTA)*, New York University, New York, pp. 536-537.

Higgins, T., Hall,R. and Dessouky, M. (1999). *Comparison of Attributes and Characteristics of Strategic Ports to Agile Port Models.* Department of Industrial and Systems Engineering University of Southern California, Los Angeles.

Holguin-Veras, J. and Walton, C.M. (1996). *State of the Practice of Information Technology at Marine Container Ports*, Transportation Research Record, No.1522 National Academy Press, Washington D.C.

Holguin-Veras, J., and Walton, C.M. (1996). On the Development of A Computer System to Simulate Port Operations Considering Priorities, Proceedings of the 1996 Winter Simulation Conference, Coronado, CA, December, pp.471 - 1478.

Igeilska,J. (1996). The Impact of Logistics on the technical Performance of Ships: A case study, *Proceeding of the 3rd European Roundtable Conference on SSS*, Bergen, Norway, June, pp.130-140.

Ioanou, P.A., Kosmatopoulos, E.B., Jula, H., Collinge, A., Liu, C.-I. , and Asef-Vaziri, A. (2000). *Cargo Handling Technologies*, *Final Report for the Centre for Commercial Deployment of Transportation Technologies*, California Center for Advanced Transportation Technologies.

Khoshnevis, B., and Asef-Vaziri, A. (2000). 3D Virtual and Physical Simulation of Automated Container Terminal and Analysis of Impact on Inland Transportation. METRANS Report, University of Southern California, Los Angeles, Ca. US.

Le-Griffin, H. and Moore, J. (2006). *Potential impact of Short Sea Shipping in the Southern California Region,* METRANS Project 65-A0047 University of Southern California University Park.

Meersmans ,P. J. M., and Wagelsmans, A. P. M. (2001). *Dynamic Scheduling of Handling Equipment at Automated Container Terminals.* Erasmus Research Institute of Management (ERIM), Erasmus University Rotterdam.

Murty KG, Liu J, Wan *YW*, Linn R (2005). A decision support system for operations in a container terminal. *Journal of Decision support systems* 39, pp. 309-332.

Ottjes, J.A. Veeke H., Duinkerken,M., Rijsenbrij, J., and Lodewijks,G. (2006). Simulation of a multiterminal system for container handling. Kim,H. and Günther, H.O (eds) Container Terminals and Cargo Systems. Heidelberg, Germany: Springer.

Ramstedt, L. (2005); Transport chain characteristics and influential factors, Licentiate Thesis, BTH series 2005.11. Blekinge Institute of Technology.

Rardin, L.R. (2000). *Optimization in Operations Research*, Saddle River NJ*:*Prentice Hall Inc.

Rashidi, H., and Tsang, E.P.H. (2006). Container Terminals: Scheduling decisions, their formulation and solutions, submitted to *Journal of Scheduling*.

Robson, C. (2002). *Real World Research* 2nd Edition. London, UK: Blackwell publishing.

Steenken, D., Voß, S., and Stahlbock, R. (2004) Container terminal operation and operations research - a classification and literature; *Journal of OR Spectrum* 26(1), pp, 3- 49.

Strandenes,S.P., and Marlow, P.B. (2000). Port Pricing and Competitiveness in Short Sea Shipping, *International Journal of Transport Economics* 27(3).

Vis, I.F.A. (2006). A comparative analysis of storage and retrieval equipment at a container terminal, *International Journal Production Economics* 103, pp.680–693.

Wijnolst N. and Hoek, M. (1993). *Analysis of the containership carter market*, Delft, the Netherlands: Delft University press.

Yin R. K. (1994); *Case Study Research; Design and Methods*, 2nd Edition, Newbury Park, CA: SAGE publications.

Zigic, B. and Renner, V. (1996). One new concept for container reloading on inland vessels. *Proceeding of the 3rd European Roundtable Conference on SSS,* Bergen, Norway, June pp.171-179.